536377

Final Report

submitted to

NASA

Radiation Science Program

Mission to Planet Earth

TITLE:

Studies of Ice Nucleating Aerosol Particles in Arctic Cloud Systems

NASA Grant NAG1-2063

PRINCIPAL INVESTIGATORS:

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PERIOD COVERED:

March 1998 to March 2001

SUMMARY OF RESEARCH

Research Objectives

The focus of this research is to improve the understanding of ice nucleating aerosol particles (IN) and the role they play in ice formation in Arctic clouds. IN are important for global climate issues in a variety of ways. The primary effect is their role in determining the phase (liquid or solid) of cloud particles. The microscale impact is on cloud particle size, growth rate, shape, fall speed, concentration, radiative properties, and scavenging of gases and aerosols. On a larger scale, ice formation affects the development of precipitation (rate, amount, type and distribution), latent heat release (rate and altitude), ambient humidity, the persistence of clouds, and cloud albedo.

The overall goals of our FIRE III research are to characterize the concentrations and variability of Arctic IN during the winter-spring transition, to compare IN measurements with ice concentrations in Arctic clouds, and to examine selected IN samples for particle morphology and chemical composition using electron microscope techniques to see if

there are distinguishable chemical signatures. The results can be combined with other measurements of aerosols, gaseous species, and cloud characteristics in order to understand the processes that determine the phase and concentration of cloud particles.

Accomplishments

Ice nuclei and aerosol particle instruments from CSU were installed on the NCAR C-130 research aircraft. Measurements were obtained on eight flights in the May 1998 portion of the FIRE-III Arctic Cloud Experiment. The ice nuclei measurements were made with a continuous flow diffusion (CFD) chamber, over a range of temperatures -10 to -30°C and humidities from ice saturation to water supersaturation. During selected time periods, the ice crystals that grew on ice nuclei in the chamber were sampled onto electron microscope (EM) grids using inertial separation techniques, for later examination of the nucleating particles. Samples of total aerosol (IN and non-IN) were also collected for comparative analyses.

Case studies of cloud and aerosol properties on individual flights were constructed from a wide variety of observations that were obtained during the project. Selected data were combined into summary descriptions of the clouds using information from our IN and CN measurements, C-130 aircraft data, remote sensing imagery, observations from the SHEBA ship (radar and lidar vertical profiles and time histories of clouds and stable layers, aerosol layers), and meteorological data.

Transmission electron microscope (TEM) analyses were performed on selected particle samples. These analyses were performed at CSU and by RJ Lee company. The analyses included particle size, morphology, and composition. Energy dispersive x-ray (EDX) microprobe spectra were used to determine chemical composition. Similar techniques were used for analyzing both ambient and IN particles. Descriptions of analysis methods and summaries of the results are in the publications.

Climatological type descriptions of aerosol and IN measurements were estimated by accumulating and stratifying the data and deriving population statistics. These summaries include: vertical profiles of CN and IN; IN number concentrations at different temperatures and humidities; the fraction of total particles capable of acting as IN; and the sizes and chemical compositions of Arctic IN in the spring-summer transition season.

The results of this research were presented at a number of scientific meetings, including: FIRE-III Science Data Workshops, professional society conferences, scientific colloquiums and other science workshops. The results have been published in reviewed scientific literature, including a paper in the JGR special issue on Arctic cloud studies. The papers and presentations are listed in a later section of this report.

In accordance with project reporting requirements, we submitted IN and aerosol particle data to the project archive. Ice nuclei and particle data were reviewed for quality assurance, and final versions of category one and two measurements were made available to the Langley Research Center Distributed Data Active Archive System (LaRC DAAC). Information in the archive includes narrative descriptions of the instrumentation and sampling procedures, a list of derived variables, calibration and data reduction procedures, and a discussion of data usage. The archived data are ASCII listings

(approximately one second) of IN sampling temperature, humidity, pressure, volume sample rate, number of nuclei detected, and the number concentration of CN and IN. Summaries of the single particle analyses appear in the publications.

Major Findings

Typical concentrations of CN (condensation nuclei) were ~400 cm^{-3} over extended regions and occasionally as low as ~20 cm^{-3}. Such low concentrations are usually associated with air that has been cleaned by a sequence of efficient natural scavenging mechanisms in marine locations far removed from anthropogenic influence. Concentrations of IN ranged from zero to rare very high values (hundreds per liter at -25°C), making the frequency distribution of IN highly skewed: when accumulated as 10 s average concentrations (~0.17 L), 50% were zero. Additional evidence of few IN was seen in thin low level stratus clouds at -10 to -20°C that persisted for several days at the SHEBA ice camp site. These clouds had low concentrations of ice crystals (~0.1 L^{-1}) and a few tenths g m^{-3} liquid water. Strong vertical stratifications were seen in aerosol number concentrations (<3 μm), coinciding with thermal stratifications in the atmosphere.

An unexpected and surprising observation was the rare occurrence of small regions of high IN concentrations (100's per liter) near the surface. The small extent of high IN suggests the source may be local or that higher IN might be confined within thin stable layers.

The EM analyses of Arctic aerosol particles indicated that ice nuclei a few tenths micrometer in size contained crustal materials (primarily Si) and had widely varying morphology. Many IN particles produced weak or no x-ray signatures, most likely due to the dominance of a low-molecular-weight component not detectable by the EDX system, and were probably carbonaceous. In contrast, for the total aerosol samples, S or S and Si were the dominant components; particles having no x-ray signature were relatively rare.

Summary of Activities

Year 1

The first year of research was devoted to preparing for and participating in the field project. Instrumentation from CSU was installed on the NCAR C-130 research aircraft, and measurements were obtained in the May 1998 portion of the Arctic Cloud Experiment. Modifications were made to the CFD instrument to record particle sizes (256 channel resolution) and to enable rapidly changes of the wall temperatures. Pre- and post-project calibrations were performed. Preliminary results were presented at a FIRE-III scientific workshop in Tucson and at an invited talk in Leipzig, Germany.

Year 2

In year two, the CSU data were screened for quality assurance, and archive versions of the data were prepared. Preliminary versions of these data were placed on a ftp site for access by other FIRE-III investigators and the NASA archive. Case study analyses of selected flights were begun. Laboratory tests were done to examine the performance of

the optical particle counter, the inlet particle impactor, and the CFD technique at high supersaturations. EM analyses were done on selected samples of aerosol particles and ice nucleating particles. Ensembles of IN and CN data were compiled according to altitude and water vapor supersaturation. Results of this research were presented at a FIRE-III scientific workshop in Boulder, an invited talk at NCAR (ASP colloquium), and the fall meeting of AGU in San Francisco.

Year 3

Emphasis in year three was on completing EM analyses, finishing the case study analyses, and writing scientific papers. Results of this research were presented at scientific conferences in Rolla (15th ICNAA), Reno (13th ICCP) and St. Louis (AAAR), and invited talks at Penn State University and Toronto (NARCM).

Conferences, Publications and Project Meetings

Rogers, D.C., DeMott, P.J., S.M. Kreidenweis and Y. Chen, 1998: Measurements of atmospheric ice nuclei with an airborne instrument. *Conference on Cloud Physics*, Seattle, American Meteorological Society.

Rogers, D.C., S.M. Kreidenweis and P.J. DeMott, 1999: Measurements of Ice Nucleating Aerosol Particles in the Arctic. *SHEBA/FIRE Workshop*, Tucson, Arizona.

Rogers, D.C., P.J. DeMott, S.M. Kreidenweis and Y. Chen, 1999: Methods and Issues for Study and Segregation of Ice Nuclei in the Laboratory and Atmosphere. (Invited talk) *Workshop on Atmospheric Ice Formation below the Cirrus Level*, Institute for Tropospheric Research, Leipzig, Germany.

Rogers, D.C., 1999: Measurements of Ice Nuclei. (Invited talk) NCAR Advanced Studies Program, *Summer Colloquium series, Ice Formation in the Atmosphere*, Boulder, Colorado.

Rogers, D.C., S.M. Kreidenweis, P.J. DeMott and K.V. Davidson, 1999: Airborne measurements of atmospheric ice nuclei in the Arctic. *Annual Meeting of American Geophysical Union*, San Francisco.

Rogers, D.C., S.M. Kreidenweis, P.J. DeMott and K.V. Davidson, 2000: Airborne measurements of atmospheric ice nuclei in the Arctic, *FIRE/SHEBA Workshop*, Boulder, Colorado.

Curry, J.A., P.V. Hobbs, M.D. King, D.A. Randall, P. Minnis, G.A. Isaac, J.O. Pinto, T. Uttal, A. Bucholz, D.G. Cripe, H. Gerber, C.W. Fairall, T.J. Garrett, J. Hudson, J.M. Intrieri, C. Jakob, T. Jensen, P. Lawson, D. Marcotte, L. Nguyen, P. Pilewskie, A. Rangno, D.C. Rogers, K.B. Strawbridge, F.P.J. Valero, A.G. Williams, and D. Wylie, 2000: FIRE Arctic Clouds Experiment, *Bull. Amer. Met. Soc.*, 81, 5-29.

Rogers, D.C., S.M. Kreidenweis, P.J. DeMott and K.V. Davidson, 2000: Atmospheric ice nuclei in the Arctic - airborne measurements and physico-chemical properties, *15th International Conference on Nucleation and Atmospheric Aerosols*, Rolla, Missouri, 447-450.

Rogers, D.C., S.M. Kreidenweis, and DeMott, P.J., 2000: Measurements of ice nuclei at

high supersaturations, *15th International Conference on Nucleation and Atmospheric Aerosols*, Rolla, Missouri, 443-446.

Rogers, D.C., S.M. Kreidenweis, P.J. DeMott and K.G. Davidson, 2000: Airborne studies of atmospheric ice nuclei and cloud ice formation in mid-latitude winter and Arctic spring, *13th International Conference on Clouds and Precipitation*, Reno, Nevada, 25-28.

Rogers, D.C., P.J. DeMott, S.M. Kreidenweis and K.G. Davidson, 2000, Field studies of atmospheric ice nucleating aerosol particles, *American Association for Aerosol Research*, St. Louis, 121.

Rogers, D.C., S.M. Kreidenweis, P.J. DeMott and K.V. Davidson, 2000: Airborne studies of ice nuclei and cloud ice formation. (Invited talk), Pennsylvania State University.

Rogers, D.C., S.M. Kreidenweis and P.J. DeMott, 2001: Ice forming nuclei and nucleation of ice crystals. (Invited talk), *Northern Aerosol Regional Climate Modeling Workshop*, Toronto.

Rogers, D.C., P.J. DeMott, S.M. Kreidenweis and Y. Chen, 2001: A continuous flow diffusion chamber for airborne measurements of ice nuclei. *J. Atmos. Oceanic Techn.*, 18, 725-741.

Rogers, D.C., P.J. DeMott, and S.M. Kreidenweis, 2001: Measurements of ice nucleating aerosol particles in the Arctic. *J. Geophys. Res.*, (in press).

Inventions

No invention or new process which might be patentable was conceived or reduced to practice by personnel working under this award.

July 9, 2001

Dr. Victor E. Delnore
M/S 483
NASA Langley Research Center
Hampton, VA 23681-5841

Re: Grant NAG1-2063, Final Report

Dear Dr. Delnore,

Attached is the final report for NASA grant NAG1-2063, *"Studies of Ice Nucleating Aerosol Particles in Arctic Cloud Systems"*. The report summarizes three years' research that began with airborne measurements from the NCAR C-130 aircraft during the FIRE3 Arctic Clouds Experiment in 1998.

Sincerely,

David C. Rogers

David C. Rogers
Research Scientist